PROGRESS IN GIS CHANGE DETECTION ABILITY

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Abstract

Basic geometric algorithms, like heuristic polynomial equations, which are still in use, namely for the geometric rectification and/or transformation of remote sensing data into GIS systems, lack reliability. Due to the characteristic error propagation, heuristic polynomial equations may cause extreme distortions in GIS data, which, beside others, can become the reason for a complete misinterpretation of environmental phenomenas, in particular in view of Change Detection. On the other hand mathematically strict algorithms, which are complex in handling and time consuming, often are not really required for practical purposes. Therefore it is the intention of this paper, to present reliable algorithms, suited for the geometric transformation of radar remote sensing data into GIS systems, which compromise between heuristic polynomial equations and mathematically strict approaches. Finally methods and results carried out for digital image rectification are dealt with, as well as qualitative aspects of the final products (radar mosaics and radar image maps).

Keywords: Algorithm, Change Detection, GIS / LIS, Radarblockadjustment, Radar Mosaic

1. INTRODUCTION

The main reason for geometric image processing is, to derive geometric correct positions of the pixels, which contain surface related information as greyvalues, in order to achieve a reliable geocoding of geometric distorted remote sensing image data for the correlation with GIS- or map-data.
Thus the full success of a radar mapping campaign depends on the ability of a proper rectification of geometric distortions, in particular to avoid misinterpretations due to mismatching within a Geo-Informationsystem (GIS).
Main objectives in this context are the providings of suited algorithms and software, necessary to achieve (digital) geometric precise radarmaps or radar orthophotos, in view of
- GIS Integration
- mosaicing,
- sensor comparison,
- updating etc..

This task has been solved by geometric improvement of slant- as well as ground range radar image data, based on suited algorithms, which at least allow to calculate 3 dimensional and not only 2 dimensional ground control point coordinates.

2. RADARGRAMMETRIC APPROACHES AND RESULTS

The transformation of imagedata into map or GIS-data is an interpolation problem. There are in principal 3 categories of algorithms to solve the geometric problems for remote sensing imagery, including radar-images:
- non-parametric interpolation methods
- (physical) parametric methods and
- combined approaches.

The interpolation process can be based on
- ground control point- and/or texture information,
- housekeeping data (like airborne GPS etc.) and on
- combinations of both types of data.

Ground control point data is derived from known numeric coordinate values, from GPS, from or maps and from imagecoordinates of corresponding points, which can be verified manually, but increasingly by interactive digital (relative and absolute) correlation techniques.

2.1 Non-parametric interpolation methods

This are namely
- polynomial equations,
- spline functions,
- interpolation in a stochastic field, like moving average, weighted mean, linear prediction etc..

For SAR images of flat terrain 2 dimensional heuristic polynomial equations like

$$x' = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2$$

and

$$y' = b_0 + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2$$

for limited areas of approximately 40x40 km² of flat terrain and stable flight conditions already allow to obtain accuracies of about ±1 pixel for ground control points.

The advantages of 2 dimensional polynomial equations beside others are

- the didactic value for introducing into digital geometric image processing,
- suitability for quick programming
- satisfying for limited areas of flat terrain
- support for approximate value determination
- support for blunder detection

Some disadvantages of 2 dimensional polynomials are

- arbitrariness
- limited area of validation
- a blockadjustment based on arbitrary polynomial equations of higher than first order shows an extremely bad error propagation.
- restriction for 2 dimensions.

2.2 PHYSICAL PARAMETRIC APPROACH

In order to formulate strict geometric algorithms for SAR- and SLAR radar imagery, a physical parametric solution is envisaged, which allows to calculate

- the global and local behaviour of the sensor position and attitudes,
- 3dimensional ground control point coordinates and
- computation of imagecoordinates for 3 dimensional output raster data (resampling).

Extended collinearity equations as derived by the authors (see Konecny, Schuhr, 1986) fulfil this geometric requirements for radar images. For the abscisses values x' of the image coordinates the following constraint is valid:

$$0 = -kx \frac{a_{11j}(x_i - \mathrm{DELTAX} - x'_{oj}) + a_{12j}(y_i - \mathrm{DELTAY} - y'_{oj}) + a_{13j}(z - z'_{oj})}{a_{31j}(x_i - \mathrm{DELTAX} - x'_{oj}) + a_{32j}(y_i - \mathrm{DELTAY} - y'_{oj}) + a_{33j}(z - z'_{oj})}$$

For the groundrange ordinate values y'gr follows:

$$y'_{gr} = -ky \frac{a_{21j}(x_i - \mathrm{DELTAX} - x'_{oj}) + a_{22j}(y_i - \mathrm{DELTAY} - y'_{oj}) + a_{23j}(z - z'_{oj})}{a_{31j}(x_i - \mathrm{DELTAX} - x'_{oj}) + a_{32j}(y_i - \mathrm{DELTAY} - y'_{oj}) + a_{33j}(z - z'_{oj})}$$

Notice, the z value carries no index, because it represents the (unknown) (constant) terrainheight for the groundrange image calculation, while DELTAX and DELTAY depend on the individual terrainheight zi. To achieve the measured y' value in the ground range image, the near range distance r'o has to be subtracted from the computed groundrange ordinate value y'gr

$y' = y'gr - ro'$

While for slant range ordinates follows

$$y'sl = \sqrt{y'gr^2 + ky^2}$$

With sufficient approximation is valid:

$$\mathrm{DELTAX} = \frac{\sqrt{(x_i - x'_{oj})^2 + (y_i - y'_{oj})^2} - \sqrt{(z_i - z'_{oj})^2 + (y_i - y'_{oj})^2 + (z_i - z'_{oj})^2 - h^2}}{\sqrt{(x_i - x'_{oj})^2 + (y_i - y'_{oj})^2}} \, (x_i - x'_{oj})$$

$$= F \times (x_i - x'_{oj})$$

$$\mathrm{DELTAY} = F \times (y_i - y'_{oj})$$

As usual

xi,yi,zi =3dimensional object point coordinates

xo'j,yo'j,zo'j =instantaneous sensor position

z =terrain height chosen for groundrange calculation

h =zo'j - z

kx, ky = equivalent focal length

a11j until a33j = instantaneous rotation coefficients, which ,as sinusoidal functions, depend on roll, pitch and yaw values as a function of x' ("= time"):

$$\mathrm{roll} = \mathrm{omega} = \Omega j = \Omega 0 + \Omega 1 \cdot x'i + \Omega 2 \cdot x'i^2$$

$$\mathrm{pitch} = \mathrm{phi} = \Phi j = \Phi 0 + \Phi 1 \cdot x'i + \Phi 2 \cdot x'i^2$$

$$\mathrm{yaw} = \mathrm{kappa} = kj = k0 + k1 \cdot x'i + k2 \cdot x'i^2$$

$$xo'j = x'o0 + x'o1 \cdot x'i + x'o2 \cdot x'i^2$$

$$yo'j = y'o0 + y'o1 \cdot x'i + y'o2 \cdot x'i^2$$

$$zo'j = z'o0 + z'o1 \cdot x'i + z'o2 \cdot x'i^2$$

This expressions are valid for the general formulation of SLAR- and SAR- image geometry.

While deviations in the sensor position directly affect the SAR image geometry, general attitude values only, but not changes of attitudes do influence the SAR image geometry, which is in opposite to the direct influence of the unstable sensor behaviour in the SLAR image geometry.

Linearized collinearity equations allow to derive polynomial equations of equivalent content, which are valid under particular flight behaviour assumptions. The following observation equations have been derived from linearized equivalent radar collinearity equations ,for second order variations of the orientation elements after the elimination of high correlated terms and after transition to ground coordinates. For a block consisting of overlapping radar strips, the complete observation equations, which include the calculation of 3dimensional point coordinates are

$$\begin{aligned} vx'i = {} & A0 + A1 \cdot yi + A2 \cdot xi + A3 \cdot xi^2 \\ & + A4 \cdot dxi - x'i \text{ measured} \end{aligned}$$

$$\begin{aligned} vy'i = {} & B0 + B1 \cdot yi + B2 \cdot xi + B3 \cdot xi^2 \\ & + B4 \cdot xi \cdot yi + B5 \cdot yi^2 + B6 \cdot xi^2 \cdot yi + B7 \cdot xi{*}{*}3/yi \\ & + B8 \cdot xi{*}{*}4/yi \\ & + B9\, zi/yi + B10 \cdot xi \cdot zi/yi + B11 \cdot xi^2 \cdot zi/yi \\ & + B12 \cdot dyi + B13 \cdot dzi - y'i \text{ measured} \end{aligned}$$

For single strips these equations at least have to be reduced for the unknown parameter for the terrainheight zi. For flat terrain the terms depending on the terrain height zi are zero. The principle idea of this method for the formulation of algorithms goes back to Baker (1975), who applied it on line scanner imagery, which has been modified for SLAR and SAR image geometry. These equations can already be used without the knowledge of the content of the parameters A0 to A4, respectively B0 to B13, which are stated as follows:

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A0= -kx - x'o0/h - kx - Φ0
A1= kx-k0/h
A2= kx²-x'o1/h²

A3= kx**3 - x'o2/h**3
A4= kx/h
B0=-ky-y'o0/h+r'o-z'o0/h-ky-Ω0-r'o-dz/h+r'o-dky-dro'
B1=-ky-z'o0/h²+r'o-Ω0 /h+ky/h²-dz+(-ky/h+1/h) -dky
B2= -kx-ky-y'o1/h²   +kx -r'o-z'o1/h²
B3= -kx²-ky-y'o2/h**3+kx²-ro-z'o2/h**3
B4= -kx-ky-z'o1/h**3
B5= -ky-Ω0/h²
B6= -kx²-ky-y'o2/h**4
B7= 2-kx**3-ky-z'o2-z'o1/h**4
B8= kx**4-ky-z'o2²/h**5
B9= -ky-z'o0/h
B10= -kx-ky-z'o1/h²
B11= -kx²-ky-z'o2/h**3
B12=ky/h
B13=ky-(zi-z'o0-kx-z'o1-xi/h-kx²-z'o1-xi²/h²)/(h-yi)
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This approach can be extended by variation of the sensor behaviour, in particular by calculating for the "real flight path", as gained from housekeeping GPS and by additional parameters , including the introduction of the Doppler information of the Radar-image, to fit smoother to the ground control point field. As compared to heuristic approaches, which are still in use even for very advanced image processing devices, arbitrariness is subdued and the 3rd dimension can be calculated.

For recent radar campaigns the polynomial approach as derived from equivalent collinearity equations, showed an accuracy of approximately ± 10m.
To use the advantages of existing bundle block adjustment software for conventional photography, an approximate transformation of the radar geometry into the conventional image geometry and vice versa also successfully has been carried out. The modified BINGO- program of the Institute for Photogrammetry of the University of Hannover according to Kruck et al. (1986), for 47 ground control points allowed to obtain an accuracy of about ±2.5 pixels for a SIR -B image of the testsite Freiburg, as carried out by WIGGENHAGEN.

2.3 Combined Approaches

The following method gives an example for a combined approach between parametric and non-parametric solutions: Radar image coordinates (xi', yi') for ground coordinates of particular points with known object coordinates (xi, yi, zi), including output pixels (e.g., anchor points), can be calculated from known ground control points (xp, yp, zp). Supposing, roll-, pitch- and yaw-values are neglectable and under the condition, the object coordinate system and the radar image coordinate system are in parallel, the following approach approximately is valid:

xi'=xp'+kx((xi-xp)/h)

yi'=yp'-ky((yi-DELTAYi-yo'i)/(z-zo'i)
  -(yp-DELTAYp-yo'p)/(z-zo'p))

with DELTAYi= h (zi-z) / (yi-yo'j).

For the calculation of DELTAYp the index "i" has to be replaced by "p". The results improve by applying this approach onto surrounding control points. The deviations of the resulting image coordinate pairs for xi' and yi' can be eliminated by the weighted mean approach. To apply this method, a great amount of ground control points is needed, which can be determined by radar block adjustment etc..

3. RADAR MAPS AND RADAR ORTHO-PHOTOS

3.1 Quicklook results

The proposed SAR image standard product is ground range imagery, because it is accepted by the user community. This output result for areas with flat terrain might even be considered as a final product, in particular for ocean regions and for coastal sites.

3.2 Radar orthophoto

For tasks, which require map accuracy(usually ±1...3 pixels, see DOYLE (1975) and KONECNY et al.(1984b)), like
- GIS-input
- mosaicing,
- multisensor imagery and
- change detection etc.,

for hilly and mountainous terrain, a digital geometric pixel by pixel image restitution, including terrain height effects is needed, preferable applying the indirect rectification method. To handle larger output blocks and to calculate for regional or even particular pixel wise terrain heights, according to suggestions of Egels and Massou d'Autume of the IGN (France) and Konecny (1985) the following method for digital image rectification has been established:

Step 1 and 2: anchor point determination:

1. For minimum and for maximum terrain height

(e.g., within the DTM to be used) the SAR image coordinates of the anchor points are determined based on a reliable approach.
2. The proper imagecoordinates of the anchor points are calculated from linear interpolation in between the image coordinates of step 1., using the actual terrainheight (as interpolated from a DTM) as the argument for interpolation.

Step 3 and 4: pixel interpolation:
3. For minimum and for maximum terrain height the SAR image coordinates of the output pixels continuously are determined by bilinear interpolation within the corresponding output pixel block defined by 4 corresponding anchor points.
4. The proper imagecoordinates of the output pixels are calculated from linear interpolation in between the image coordinates as stated under 3., using the actual terrain-height as the argument for interpolation.

The orthophoto derived, may also be generated with a digitally determined coordinate grid, as well as edge or gradient enhancement procedures may be utilised to generate quasi line maps. At the Institute for Photogrammetry of the University of Hannover, a new standard product has been achieved for hilly terrain, in order to verify a reliable geocoding of radar imagery for, e.g., GIS-input. The digital data is transformed into the GIS- coordinate system, which includes absolute positioning, north orientation and a uniform scale. The DEM- influences are already rectified, as well as changes in attitudes.

4. QUALITATIVE ASPECTS OF RADAR IMAGE PRODUCTS

Due to relative low geometric resolution, radar missions for topographic mapping purposes should concentrate on permanently clouded areas only.
According to Ulaby the equivalent pixel size for, e. g., a nominal 6 m radar resolution for 5 looks approximately is 12 m. Therefore preferable high resolution radar should be flown. For further topographic applications it is highly recommended to compare samples of radar images with images from optical sensors, like conventional aerial photography of the same area, which for the most purposes gives an idea of the superiority of conventional aerial photography for topographic detail interpretation (in particular with respect to single buildings). The look direction must be chosen with respect to topography, taking into account the final appearance of the pseudo plastic effect in the radar orthophoto map. In order to overcome radar shadow, opposite side look direction radar in addition to same side stereo radar should be promoted.

For (digital) mosaicing purposes the acceptable depression angle, for image parts used for the mosaic, in particular depends on the topography.

5. CONCLUSION

The geometric approach used, should follow the radar projection laws and not only empirical functions, like arbitrary polynomial equations. For the future a great improvement in this field is anticipated. Radar mosaics and Radar block adjustment can bridge areas with rare ground control points. If this gap extends about one strip width, polynomial equations used for an image to image registration, due to the error propagation, should be of first order. From housekeeping GPS the flight path data already can be achieved with acceptable accuracy, which within the radar block adjustment allows to use a more realistic formulation of the flight behaviour within the radar block adjustment procedure. Also inflight GPS will replace ground control to a great extend.

6. REFERENCES

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